

Accuracy of optical interocclusal registration using an intraoral scanner

Mami Okamoto, Norimasa Tanabe, Shota Fukazawa, Yutaro Oyamada, Hisatomo Kondo *

Department of Prosthodontics and Oral Implantology, School of Dentistry, Iwate Medical University, Morioka, Japan

Abstract

Purpose: This study aimed to clarify the effect of occlusal force on appropriate optical interocclusal registration in clinical practice, considering periodontal ligament and jawbone deformation.

Methods: Forty participants with natural, healthy dentition were enrolled (19 men and 21 women; mean age, 27.7 ± 2.0 years). A TRIOS3 intraoral scanner was used to scan the right lateral first premolar to the second molar areas of the upper and lower jaws. During scanning for interocclusal registration, participants were instructed to “bite normally,” “bite lightly,” and “bite strongly” to obtain data for the three occlusal patterns. The standard triangulated language (STL) data for each occlusion condition were superimposed using the appropriate software, following which the tooth displacement was calculated. The conventional method was also used to record the occlusal contact area for a silicone model using a dental contact analyzer.

Results: Tooth displacement was significantly lower for the strong-bite condition than for the weak-bite condition (0.018 mm vs. 0.028 mm, $P < 0.05$). As the occlusal force increased, the occlusal contact area also increased, and significant differences were observed among the different occlusal conditions ($P < 0.05$).

Conclusions: Occlusal contact area changed depending on the bite force when using the silicone impression or optical intraoral scanning methods. Moreover, using optical impression methods in “strong bite force” may reduce the deviation and allow for stable interocclusal registration.

Keywords: Optical interocclusal registration, Intraoral scan, Prostheses, Occlusal force, Tooth displacement

Received 14 August 2022, Accepted 4 January 2023, Available online mmm dd, yyyy

1. Introduction

Recent developments in intraoral scanning technology allow digital scans of the oral cavity, and guide the fabrication of prostheses using computer-aided design and manufacturing (CAD/CAM) devices, which are now more efficient than conventional methods[1,2]. Intraoral scanners can also be used for patients with trismus or sensitive vomiting reflex, and conventional impression methods are not always appropriate for such patients.

Several studies have investigated the accuracy of fabricated crowns based on data obtained from optical impressions[3–5]. A few studies have also compared interocclusal registrations obtained using intraoral scanners with those from conventional methods[6]. However, in clinical practice, factors such as occlusal forces, tooth loss patterns, material properties, saliva, and operator experience can affect the accuracy of interocclusal registration. Therefore, occlusal adjustment is required in many cases, even when crowns with a high accuracy of fit to the abutment teeth are fabricated. Obtaining

accurate interocclusal registration is necessary to reduce the need for occlusal adjustment.

Interocclusal registration is performed in the intercuspal position, in which the upper and lower jaw dentition are in contact at most sites, and the jaw position is stable. Conventional methods require the use of wax or silicone impression materials to maintain the mandibular position[7]. A commonly used silicone impression material (polyvinyl siloxane) was placed on the occlusal surface with the mouth open, following which the teeth were occluded. After interocclusal registration, the excess material corresponding to the undercut was trimmed, and its fit was confirmed on the model. It has a short curing time, which reduces the burden on the patient by reducing the intraoral retention time. In addition, these materials exhibit a high hardness index, allowing the operator to obtain a more accurate interocclusal registration. However, deformation of the material caused by dimensional changes affects the occlusal adjustment of the prosthesis.

An interocclusal registration of the optical impression was performed by superimposing the images of the lateral scan and images of the upper and lower dentition. In contrast to conventional methods, optical impression methods do not require registration material. Therefore, there is no curing time or risk of mandibular displacement. In general, different intraoral scanners have different algorithms and inspection software, which affect the accuracy[8]. On the other hand,

DOI: https://doi.org/10.2186/jpr.JPR_D_22_00213

*Corresponding author: Hisatomo Kondo, Department of Prosthodontics and Oral Implantology, School of Dentistry, Iwate Medical University, 19-1 Uchimaru, Morioka, Iwate 020-8505, Japan.

E-mail address: hisakondo@gmail.com

Copyright: © **** Japan Prosthodontic Society. All rights reserved.

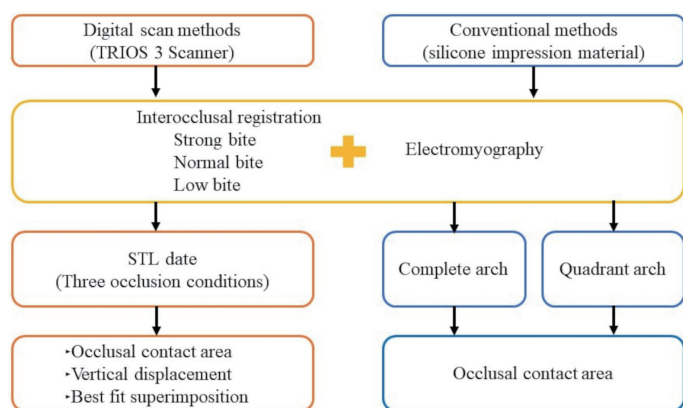


Fig. 1. Flow chart of the study

in the conventional method using silicone impression materials, transillumination, thickness of the material, and other factors may affect the interocclusal registration process. Previous studies have compared the interocclusal registration from a plaster model (obtained using the conventional method) with the optical interocclusal registration (obtained using an intraoral scanner). It was reported that models obtained using intraoral scanning have a greater accuracy than those obtained using conventional methods[6]. It has also been reported that prostheses based on optical impression using an intraoral scanner are more accurate than those fabricated based on conventional method using silicone impression materials[9,10]. However, most of these studies used models composed of dental plaster[11–14]. Thus, the accuracy of interocclusal registration based on intraoral scans remains to be validated in clinical practice. Furthermore, we believe there are differences among clinicians in the interpretation of bite force (especially when the patient is asked to perform a “normal bite,” since some patients have a strong bite, while others have a weak bite).

Therefore, this study aimed to evaluate the effect of occlusal force on appropriate optical interocclusal registration, considering the periodontal ligament and jawbone deformities. The null hypothesis was that there would be no difference in the accuracy of interocclusal registration based on imaging data in the “normal bite,” “weak bite,” and “strong bite” conditions.

2. Material and Methods

2.1. Participants

Forty participants who consented to participate in the study were enrolled (19 men and 21 women; mean age, 27.7 ± 2.0 years). The inclusion criteria were healthy natural dentition (Eichner classification A1), no tooth mobility, and stable intercuspal position. The exclusion criteria were periodontal disease with tooth mobility, Eichner classification A2 to C3, current orthodontic treatment, abnormalities in jaw movement, and disorders of temporomandibular joint. The recruited participants provided written informed consent. All experimental procedures were approved by the Ethics Committee of Iwate Medical University (approval no. 01343). The experimental methods used in this study are shown using a flowchart (Fig. 1)

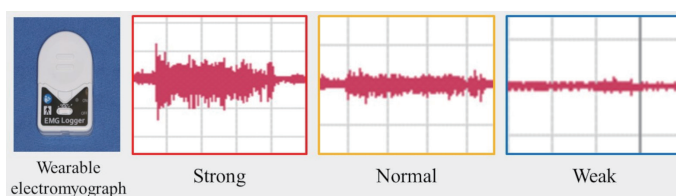


Fig. 2. Electromyograph and electromyogram. An example of wearable electromyographs and muscle activity is shown.

2.2. Optical impressions

Optical impressions were obtained by a single operator in the same clinical environment (the same dental unit, chair, and head position) for each patient. First, an intraoral scanner (TRIOS3, 3Shape, Copenhagen, Denmark)[15–20] was used to scan the right lateral first premolar to second molar areas of the upper and lower jaws in accordance with the protocol supplied by the manufacturer. For all participants, scanning was performed starting with the occlusal plane, followed by the lingual and buccal planes. After scanning the upper and lower jaws, interocclusal registration was obtained by scanning the lateral surfaces of the premolars and molars, while maintaining the intercuspal position.

2.3. Electromyography

During scanning for the interocclusal registration record, participants were provided with the following instructions: “Please bite as normal,” “Please bite lightly,” and “Please bite strongly.” All participants received instructions regarding the requirements for the three occlusal patterns prior to the interocclusal registration record. Electromyography was performed at the time of scanning. The maximum voluntary contraction (MVC) was set to 100% for calibration. After cleansing the skin, electrodes were attached to the area of the right masseter muscle to record the occlusal force, and the duration for each of the three occlusal conditions was recorded. Data were obtained using a wearable electromyograph (GC Corporation, Tokyo, Japan) consisting of electrodes, an amplifier, and a 12-bit analog-to-digital (A/D) converter with a sampling frequency of 1 kHz, a 16-bit CPU, a 3.7 V coin-shaped lithium battery, and a microSD card. The dimensions of the device were $38.3 \times 24.4 \times 10$ mm, and its weight was 9.5g[21] (Fig. 2). Data related to muscle activity were compared between the three occlusal conditions.

2.4. Interocclusal registration record

In the conventional method, silicone impression material (Blue Silicone Low Flow, GC Corporation, Tokyo, Japan) was used for interocclusal registration in accordance with the protocol supplied by the manufacturer. The silicone impression material was placed on the occlusal surface, and the participants were instructed to bite gently and hold this position for one minute before removing the material from the oral cavity. For obtaining optical impressions, the conventional method was used once for each occlusal condition with the following instructions: “Please bite as normal,” “Please bite lightly,” and “Please bite strongly.” The occlusal contact area recorded on the silicone impression material was analyzed using a dental contact analyzer (Bite-EYE BE-I; GC Corporation, Tokyo, Japan)[22,23] (Fig. 3). Data for the three occlusal conditions obtained using the conventional method were also compared (Fig. 3). The occlusal contact

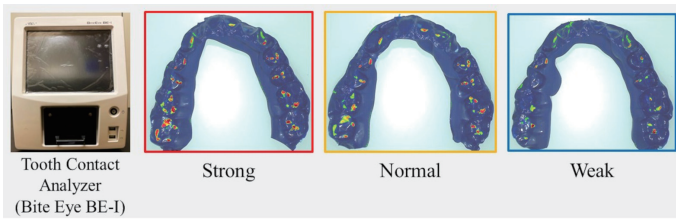


Fig. 3. Tooth contact analyzer and occlusal contact area. An example of a tooth contact analyzer and an occlusal contact area is shown.

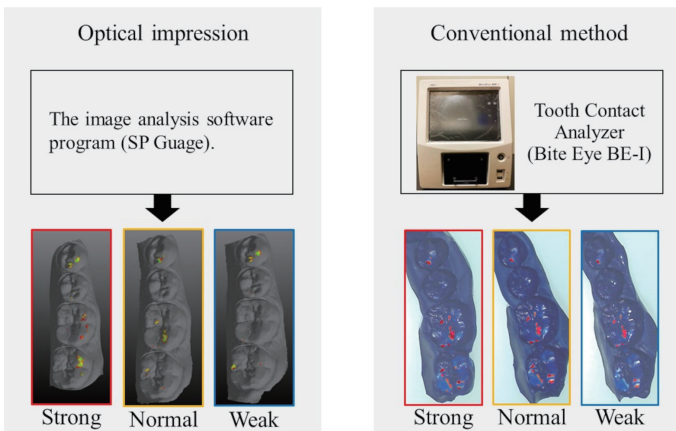


Fig. 4. Tooth contact analyzer and occlusal contact area from the first premolar to the second molar. Optical impression: The occlusal contact area was calculated using an image analysis software. Conventional method: The occlusal contact area was calculated using a tooth contact analyzer. An example of occlusal contact area from the first premolar to the second molar is shown.

data for each of the three conditions obtained using the optical and conventional methods were also compared (**Fig. 4**).

2.5. Vertical displacement

Vertical distances between the buccal cervical lines of the upper and lower teeth were measured using the 3Shape Dental System (Copenhagen, Denmark). Using a value of 0 for “normal bite” as the reference, we calculated the degree of displacement for the “strong bite” and “weak bite” conditions (**Fig. 5**).

2.6. Three-dimensional tooth displacement

Imaging data for the three patterns of interocclusal registration obtained using optical impression methods were obtained in standard triangulated language (STL) format. Data for each occlusal condition were trimmed using appropriate software (Meshmixer, Autodesk, San Rafael, California, USA), and only the tooth part was extracted. The trimmed data (STL) were imported into the image analysis software (SP Gauge, ARMONICOS, Shizuoka, Japan), and the STL data under each occlusal condition were superimposed using a best-fit algorithm[24,25]. After superimposition, three-dimensional tooth displacement was calculated for each condition (**Fig. 6**).

2.7. Sample size

G Power software (version 3.1.9.6; Heinrich Heine-Universität,

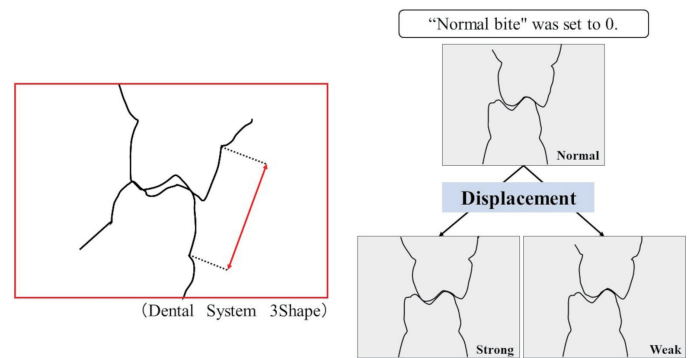


Fig. 5. Vertical displacement. The double-headed red arrow (left panel) represents the vertical distance between the buccal cervical lines of the upper and lower teeth. Measurements were obtained for cross sections in which at least two or more occlusal contacts could be confirmed. Using a value of 0 for “normal bite” as the reference, we calculated the degree of displacement for the “strong bite” and “weak bite” conditions.

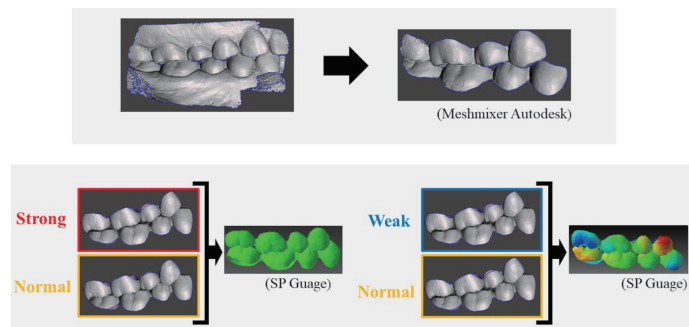


Fig. 6. Three-dimensional tooth displacement. The standard triangulated language (STL) data for each occlusal condition were trimmed using the software, and only tooth-related data were extracted. The STL data were then superimposed using a software program and the displacement of the teeth was calculated.

Dusseldorf, Germany) was used to calculate the sample size. The sample size was calculated as 40 participants based on an α of 0.05, power of 95%, and effect size of 0.6.

2.8. Statistical analysis

The optical and conventional methods were used only once, considering the potential for muscle fatigue among the participants.

The SPSS software (SPSS Statistics Desktop Version 24.0, IBM Japan, Tokyo, Japan) was used for statistical analysis. Comparisons of occlusal force and occlusal contact area for the three occlusal conditions were performed using Friedman tests, followed by Bonferroni correction for multiple comparisons. Vertical and three-dimensional displacement data were analyzed using the Wilcoxon signed-rank test. The level of statistical significance was set at $P < 0.05$.

3. Results

3.1. Occlusal force

Based on the electromyography data, the average MVC values for the strong, normal, and weak bite conditions were 40, 17, and

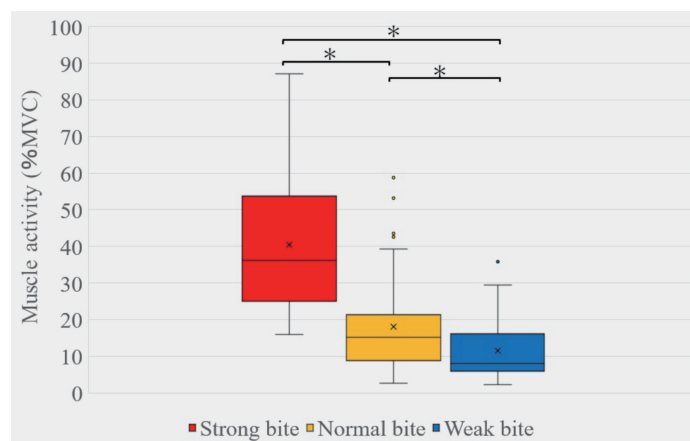


Fig. 7. The comparison of muscle activity under the different occlusal conditions. The muscle activity under different occlusal conditions was assessed using a wearable electromyograph. Significant differences were found among the groups ($P<0.05$).

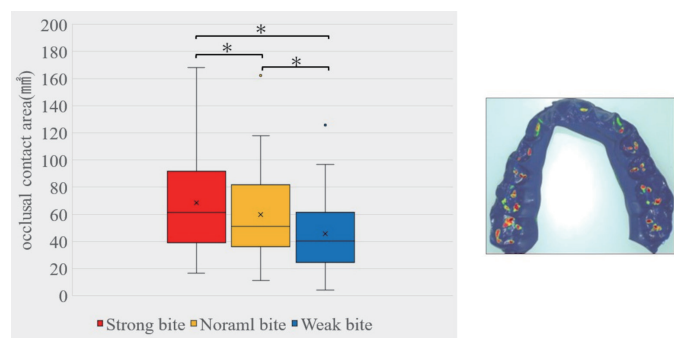


Fig. 8. The comparison of occlusal contact area under different occlusal conditions. The occlusal contact area under different occlusal conditions recorded on the silicone impression material was analyzed using dental contact analysis. Significant differences were found among the groups ($P<0.05$).

11%, respectively. Significant differences were observed between the strong and normal conditions, strong and weak conditions, and normal and weak conditions ($P<0.05$) (**Fig. 7**).

3.2. Occlusal contact area

According to our analysis of data obtained using the silicone impression material, the average occlusal contact areas for the strong, normal, and weak bite conditions were 68.45, 59.66, and 45.72 mm², respectively. Thus, occlusal contact areas tended to be larger for stronger bite forces. Significant differences were observed between the strong and normal conditions, strong and weak conditions, and normal and weak conditions ($P<0.05$) (**Fig. 8**). The occlusal contact area data obtained using the optical impression method also tended to be larger for stronger occlusal forces. However, no significant differences were observed in the occlusal contact area obtained using optical impression (**Fig. 9**).

3.3. Vertical displacement

When the normal bite was set to 0 as a reference, the vertical displacement values for strong bites tended to be more negative

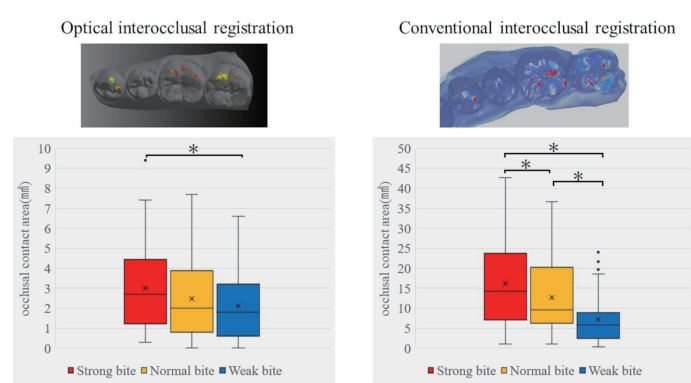


Fig. 9. The comparison of occlusal contact area from the first premolar to the second molar under different occlusal conditions. The graph on the left shows the occlusal contact area obtained by optical impression, and the graph on the right shows the occlusal contact area obtained by the conventional method using a silicone impression material. With the conventional method, a significant difference was found among all groups. Some significant differences were observed in the optical impression ($P<0.05$).

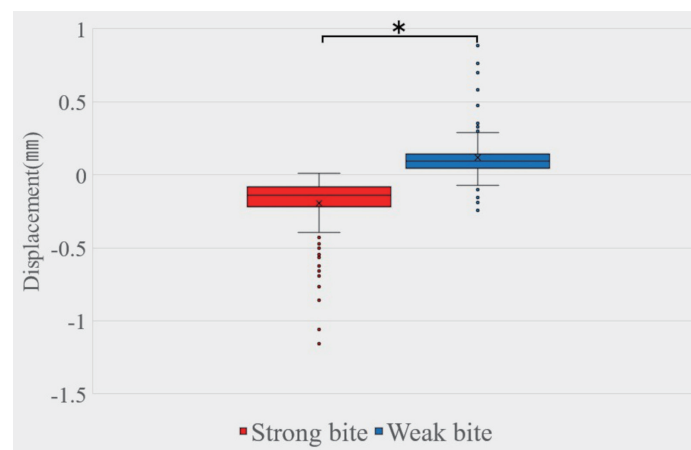


Fig. 10. The comparison of vertical displacement during biting. The extent of displacement of the vertical distance between the buccal cervical line of the upper and lower teeth is shown. A significant difference was observed between the groups ($P<0.05$).

(−0.19 mm), while those for weak bites tended to be more positive (+0.12 mm). The amount of displacement tended to be larger for the strong-bite condition than for the weak-bite condition. Significant differences in vertical displacement were observed between the strong and weak bite conditions for all the teeth ($P<0.05$) (**Figs. 10 and 11**).

3.4. Three-dimensional tooth displacement

Using the normal bite as a reference, the displacements in the strong and weak conditions were 0.018 and 0.028 mm, respectively. The degree of displacement was significantly smaller in the strong-bite condition than in the weak-bite condition ($P<0.05$) (**Fig. 12**).

4. Discussion

In this study, we aimed to evaluate the conditions for obtaining an appropriate optical interocclusal registration in clinical practice.

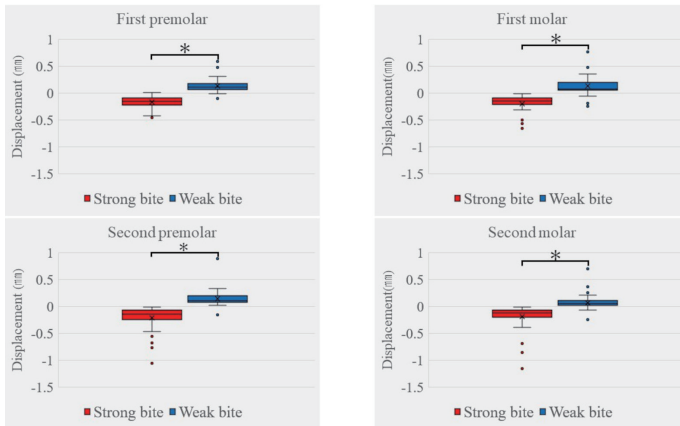


Fig. 11. The comparison of vertical displacement during biting (all teeth). The extent of displacement in the vertical distance between the buccal cervical line and the upper and lower teeth is shown for all teeth. Significant differences were found among all the teeth ($P < 0.05$).

Our findings indicated that the degree of tooth displacement differed between strong- and weak-bite conditions. Specifically, instructions to bite strongly resulted in less displacement, thus allowing stable interocclusal registration. Therefore, the null hypothesis was rejected.

4.1. Interocclusal registration

Generally, wax or silicone impression materials are used during conventional interocclusal registration. Based on this interocclusal registration record, definitive casts are mounted on an articulator and prostheses are fabricated. However, the presence of interocclusal registration material between the upper and lower teeth may affect the intercuspal position. Zimmermann et al. investigated the accuracy of habitual intercuspal registration using intraoral scanning devices. They tested the hypothesis that there is no statistically significant difference between intercuspal registration using intraoral scanning devices and conventional registration using poured model casts. The authors reported that the accuracy of intraoral scanning devices in the assessment of the relationship between maxillary and mandibular teeth were the same as in registration methods using poured model casts. In addition, compared to conventional methods, registration methods for digital buccal scans may be less susceptible to errors and easier to perform, making them more reliable when assessing the habitual intercuspal position [6][26].

Several in vitro studies have evaluated interocclusal registration using optical impressions. Edher et al. reported that occlusal contact data obtained for virtual quadrants on interocclusal scans were more sensitive than those obtained from scans for complete virtual arches [12,13]. Solaberrieta et al. reported that virtual occlusion methods provide greater accuracy than traditional physical interocclusal records [14].

4.2. Intraoral scanning

In this study, we used a TRIOS3 intraoral scanner. Several previous studies have examined the accuracy of various intraoral scanners. Diker et al. evaluated the accuracy of six representative intraoral scanners for complete-arch and 4-unit fixed dental prosthesis (FPD) preparations, in addition to testing the effect of scanning sequences.

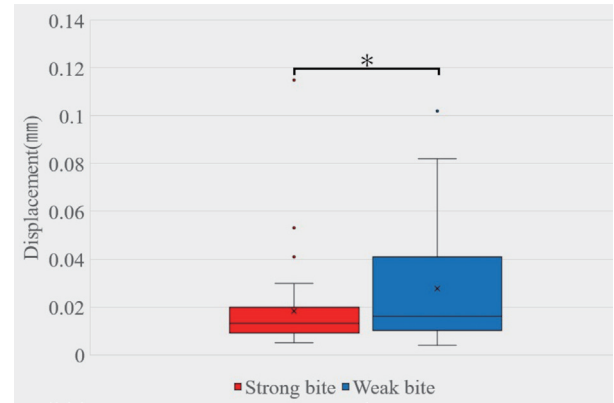


Fig. 12. Analysis by the best fit algorithm (three-dimensional tooth displacement). A comparison of the three-dimensional displacements under “strong occlusion” and “weak occlusion” conditions using the normal occlusion as a reference is shown. Significant differences were observed ($P < 0.05$).

In their study, the TRIOS scanner yielded the lowest deviation in assessing the complete arch, compared to Primescan, Virtuo Vivo, and iTero scanners [20]. Fukazawa et al. examined several accuracy parameters including trueness and precision to assess the level of error introduced by each intraoral scanner. Their results indicated that the errors of trueness measured by the second-generation 3M™ true definition scanner (TDS2) and third-generation 3M™ true definition scanner (TDS3) were higher than those by the TRIOS (TR) and laboratory scanners [19]. Therefore, the TRIOS scanner should be sufficiently accurate to evaluate the interocclusal registration.

4.3. Electromyography

In this study, we used a data-logger-type electromyograph with built-in electrodes and memory. This is one of the smallest and lightest devices available, and has the capacity to record and store measurement data for the longest consecutive duration [21,27]. This device was developed to record bruxism during sleep and it operates at a sampling frequency of 1 kHz. The analyzed data were evaluated objectively and quantitatively using dedicated software to assess the muscle activity. From the patient’s perspective, it is small and light, and can be easily operated without imposing restraints, and maintains a normal living environment [28]. Since this device has no cords, muscle activity can be measured even during the interocclusal registration process.

4.4. Occlusal force

In this study, the average MVC values for the strong-, normal-, and weak-bite conditions were 40, 17, and 11%, respectively (Fig. 7), and significant differences were observed among all conditions. When using a BIOTOP6R12 electromyography device (NEC Sanei Instruments, Ltd.), other studies have reported MVC values ranging from 33% to 52% for strong bite, and 3% to 10% for weak bite [29], and our results are in accordance with these findings. However, deviations or individual differences were still large in our study, suggesting that interpretations of bite force may vary among individuals. When patients were instructed to perform “normal bite,” some had a strong bite and some had a weak bite, suggesting that it may be difficult to control.

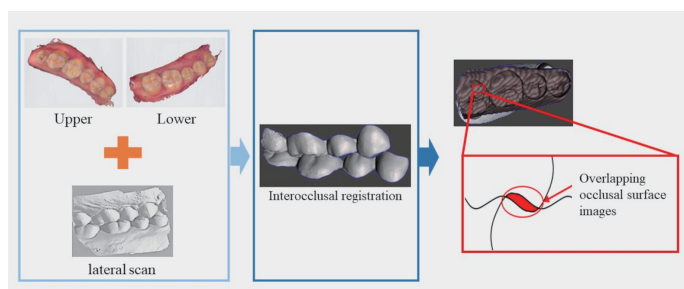


Fig. 13. Overlapping occlusal surface images. Interocclusal registration of the optical impression is performed by superimposing the images of the lateral scan and the images of the upper and lower dentition, which yields an image of the overlapping occlusal surface.

4.5. Occlusal contact area

Comparisons of occlusal contact areas under different occlusal conditions revealed that the occlusal contact area increases in response to occlusal force[30–32]. During interocclusal registration using silicone impression materials, the teeth are displaced by occlusion, causing micromovements of the occlusal contact points. In contrast, an optical scan is performed in a static state, and interocclusal registration is performed during biting. Therefore, both methods provided similar data on tooth displacement (**Fig. 9**). In addition, the optical impressions and conventional methods for measuring occlusal contact area differ in many aspects. Conventional methods are based on light transmittance at the site of actual occlusal contact. In the optical impression method, the STL data of the upper and lower dentition are superimposed on the lateral scan, and the contact area of the occlusal surfaces is calculated. Therefore, there are differences in the occlusal contact areas calculated using these two methods.

4.6. Vertical displacement

Vertical displacement tended to be larger for the strong-bite condition than for the weak-bite condition (**Figs. 10 and 11**). Several previous studies have reported that tooth displacement is caused by compression of the periodontal ligament due to occlusal force[33–35], and our results are in accordance with these findings.

4.7. Three-dimensional tooth displacement

The STL data for each occlusal condition were superimposed using a best-fit algorithm in the SP Gauge software, and the displacement was determined using normal bite data as the reference. Average tooth displacement values for the strong and weak bites were 18 and 28 μm , respectively (**Fig. 12**). When instructed to “bite strongly,” the participants could bite in a constant position, and the deviation in tooth displacement was small. Therefore, it is likely that instructions to bite strongly lead to less deviation in the interocclusal registration record than instructions to bite weakly or normally. In this study, when images of the upper and lower dentition were superimposed on the images of the lateral scan, an overlapping image was observed on the occlusal surfaces (**Fig. 13**). The same phenomenon has also been reported in other studies[6]. It does not occur with conventional methods and could be due to an unknown function or algorithm during scanning. This overlapping image may affect the accuracy of occlusal contact assessment, and should be carefully studied in the future.

4.8. Limitations of the study

In this study, we observed that a “strong bite” caused a smaller deviation in the extent of displacement compared to a “weak bite”. However, a stable interocclusal registration could still be obtained. If a prosthesis is fabricated based on interocclusal registration with a strong occlusal contact, it is possible that there would be no or weak occlusal contact. This study did not involve fabrication and evaluation of actual prostheses. In the future, prostheses should be fabricated carefully to ensure they fit properly under each occlusal condition. Since, only occlusion on the right side was targeted in this study, there is a possibility of bias, and future studies should evaluate a complete arch scan, and calibrate the scanners properly. In addition, the correlation between occlusal force, gender, and other confounding factors while using an intraoral scanner needs to be clarified. Another limitation of this study is that it targeted age groups with high occlusal force.

5. Conclusions

The current findings suggest that the occlusal contact area changes depending on the bite force while using conventional silicone impression materials and optical intraoral scanning methods for interocclusal registration. Furthermore, using optical impression methods with “strong bite force” rather than “weak occlusal force” may reduce the deviation and facilitate stable interocclusal registration.

Acknowledgements

The authors thank the study participants and the doctors who collaborated with them. This research was supported by JSPS KAKENHI (Grant number: 21K10025).

Conflicts of interest

There are no conflicts of interest to declare.

References

- [1] Ahrberg D, Lauer HC, Ahrberg M, Weigl P. Evaluation of fit and efficiency of CAD/CAM fabricated all-ceramic restorations based on direct and indirect digitalization: a double-blinded, randomized clinical trial. *Clin Oral Investig*. 2016;20:291–300. <https://doi.org/10.1007/s00784-015-1504-6>, PMID:26070435
- [2] Yuzbasioglu E, Kurt H, Turunc R, Bilir H. Comparison of digital and conventional impression techniques: evaluation of patients’ perception, treatment comfort, effectiveness and clinical outcomes. *BMC Oral Health*. 2014;14:10. <https://doi.org/10.1186/1472-6831-14-10>, PMID:24479892
- [3] Ferrini F, Sannino G, Chiola C, Capparé P, Gastaldi G, Gherlone E. Influence of Intra-Oral Scanner (I.O.S.) on The Marginal Accuracy of CAD/CAM Single Crowns. *Int J Environ Res Public Health*. 2019;16:544. <https://doi.org/10.3390/ijerph16040544>, PMID:30769768
- [4] May KB, Russell MM, Razzoog ME, Lang BR. Precision of fit: The Procera AllCeram crown. *J Prosthet Dent*. 1998;80:394–404. [https://doi.org/10.1016/S0022-3913\(98\)70002-2](https://doi.org/10.1016/S0022-3913(98)70002-2), PMID:9791784
- [5] Ng J, Ruse D, Wyatt C. A comparison of the marginal fit of crowns fabricated with digital and conventional methods. *J Prosthet Dent*. 2014;112:555–60. <https://doi.org/10.1016/j.prosdent.2013.12.002>, PMID:24630399
- [6] Iwachi Y, Tanaka S, Kamimura-Sugimura E, Baba K. Clinical evaluation of the precision of interocclusal registration by using digital and conventional techniques. *J Prosthet Dent*. 2022;128:611–7. <https://doi.org/10.1016/j.prosdent.2021.01.021>, PMID:33775391

- [7] Ghazal M, Albashaireh ZS, Kern M. The ability of different materials to reproduce accurate records of interocclusal relationships in the vertical dimension. *J Oral Rehabil.* 2008;35:816–20. <https://doi.org/10.1111/j.1365-2842.2008.01870.x>, PMID:18482345
- [8] Peroz S, Spies BC, Adali U, Beuer F, Wesemann C. Measured accuracy of intraoral scanners is highly dependent on methodical factors. *J Prosthodont Res.* 2022;66:318–25. https://doi.org/10.2186/jpr.JPR_D_21_00023, PMID:34456211
- [9] Bosniac P, Rehmann P, Wöstmann B. Comparison of an indirect impression scanning system and two direct intraoral scanning systems in vivo. *Clin Oral Investig.* 2019;23:2421–7. <https://doi.org/10.1007/s00784-018-2679-4>, PMID:30298453
- [10] Almeida e Silva JS, Erdelt K, Edelhoff D, Araújo É, Stimmelmayer M, Vieira LCC, et al. Marginal and internal fit of four-unit zirconia fixed dental prostheses based on digital and conventional impression techniques. *Clin Oral Investig.* 2014;18:515–23. <https://doi.org/10.1007/s00784-013-0987-2>, PMID:23716064
- [11] Gintaute A, Keeling AJ, Osnes CA, Zitzmann NU, Ferrari M, Joda T. Precision of maxillo-mandibular registration with intraoral scanners in vitro. *J Prosthodont Res.* 2020;64:114–9. <https://doi.org/10.1016/j.jpor.2019.05.006>, PMID:31387847
- [12] Edher F, Hannam AG, Tobias DL, Wyatt CCL. The accuracy of virtual interocclusal registration during intraoral scanning. *J Prosthet Dent.* 2018;120:904–12. <https://doi.org/10.1016/j.prosdent.2018.01.024>, PMID:29961618
- [13] Solaberrieta E, Garmendia A, Brizuela A, Otegi JR, Pradies G, Szentpétery A. Intraoral Digital Impressions for Virtual Occlusal Records: Section Quantity and Dimensions. *BioMed Res Int.* 2016;2016:1–7. <https://doi.org/10.1155/2016/7173824>, PMID:26881226
- [14] Solaberrieta E, Otegi JR, Goicoechea N, Brizuela A, Pradies G. Comparison of a conventional and virtual occlusal record. *J Prosthet Dent.* 2015;114:92–7. <https://doi.org/10.1016/j.prosdent.2015.01.009>, PMID:25858220
- [15] Renne W, Ludlow M, Fryml J, Schurch Z, Mennito A, Kessler R, et al. Evaluation of the accuracy of 7 digital scanners: an in vitro analysis based on 3-dimensional comparisons. *J Prosthet Dent.* 2017;118:36–42. <https://doi.org/10.1016/j.prosdent.2016.09.024>, PMID:28024822
- [16] Park JM, Kim RJY, Lee KW. Comparative reproducibility analysis of 6 intraoral scanners used on complex intracoronary preparations. *J Prosthet Dent.* 2020;123:113–20. <https://doi.org/10.1016/j.prosdent.2018.10.025>, PMID:31027953
- [17] Wong KY, Esquerro RJ, Chia VAP, Tan YH, Tan KBC. Three-Dimensional Accuracy of Digital Static Interocclusal Registration by Three Intraoral Scanner Systems. *J Prosthodont.* 2018;27:120–8. <https://doi.org/10.1111/jopr.12714>, PMID:29160904
- [18] Lim JH, Park JM, Kim M, Heo SJ, Myung JY. Comparison of digital intraoral scanner reproducibility and image trueness considering repetitive experience. *J Prosthet Dent.* 2018;119:225–32. <https://doi.org/10.1016/j.prosdent.2017.05.002>, PMID:28689906
- [19] Fukazawa S, Odaira C, Kondo H. Investigation of accuracy and reproducibility of abutment position by intraoral scanners. *J Prosthodont Res.* 2017;61:450–9. <https://doi.org/10.1016/j.jpor.2017.01.005>, PMID:28216020
- [20] Diker B, Tak Ö. Accuracy of six intraoral scanners for scanning complete-arch and 4-unit fixed partial dentures: an in vitro study. *J Prosthet Dent.* 2022;128:187–94. <https://doi.org/10.1016/j.prosdent.2020.12.007>, PMID:33558056
- [21] Yamaguchi T, Mikami S, Saito M, Okada K, Gotouda A. A newly developed ultraminiature wearable electromyogram system useful for analyses of masseteric activity during the whole day. *J Prosthodont Res.* 2018;62:110–5. <https://doi.org/10.1016/j.jpor.2017.04.001>, PMID:28566138
- [22] Obara R, Komiyama O, Iida T, De Laat A, Kawara M. Influence of the thickness of silicone registration material as a means for occlusal contact examination - an explorative study with different tooth clenching intensities. *J Oral Rehabil.* 2013;40:834–43. <https://doi.org/10.1111/joor.12088>, PMID:23889702
- [23] Obara R, Komiyama O, Iida T, Asano T, De Laat A, Kawara M. Influence of different narrative instructions to record the occlusal contact with silicone registration materials. *J Oral Rehabil.* 2014;41:218–25. <https://doi.org/10.1111/joor.12134>, PMID:24447195
- [24] Patzelt SBM, Emmanouilidi A, Stampf S, Strub JR, Att W. Accuracy of full-arch scans using intraoral scanners. *Clin Oral Investig.* 2014;18:1687–94. <https://doi.org/10.1007/s00784-013-1132-y>, PMID:24240949
- [25] Ender A, Mehl A. Accuracy of complete-arch dental impressions: A new method of measuring trueness and precision. *J Prosthet Dent.* 2013;109:121–8. [https://doi.org/10.1016/S0022-3913\(13\)60028-1](https://doi.org/10.1016/S0022-3913(13)60028-1), PMID:23395338
- [26] Zimmermann M, Ender A, Attin T, Mehl A. Accuracy of Buccal Scan Procedures for the Registration of Habitual Intercuspation. *Oper Dent.* 2018;43:573–80. <https://doi.org/10.2341/17-272-C>, PMID:29630481
- [27] Shochat T, Gavish A, Arons E, Hadas N, Molotsky A, Lavie P, et al. Validation of the BiteStrip screener for sleep bruxism. *Oral Surg Oral Med Oral Pathol Oral Radiol Endod.* 2007;104:e32–9. <https://doi.org/10.1016/j.tripleo.2007.03.009>, PMID:17618147
- [28] Mikami S, Yamaguchi T, Saito M, Nakajima T, Maeda M, Gotouda A. Validity of clinical diagnostic criteria for sleep bruxism by comparison with a reference standard using masseteric electromyogram obtained with an ultraminiature electromyographic device. *Sleep Biol Rhythms.* 2022;20:297–308. <https://doi.org/10.1007/s41105-021-00370-5>
- [29] Okada D. Teeth Displacements and Occlusal Contacts depending on Clenching Force. Intercuspal Position. *Nippon Hotetsu Shika Gakkai Zasshi.* 1998;42:1013–23. <https://doi.org/10.2186/jjps.42.1013>
- [30] Riise C, Ericsson SG. A clinical study of the distribution of occlusal tooth contacts in the intercuspal position at light and hard pressure in adults. *J Oral Rehabil.* 1983;10:473–80. <https://doi.org/10.1111/j.1365-2842.1983.tb01470.x>, PMID:6580404
- [31] Komiyama O, Obara R, Iida T, Asano T, Masuda M, Uchida T, et al. Comparison of direct and indirect occlusal contact examinations with different clenching intensities. *J Oral Rehabil.* 2015;42:185–91. <https://doi.org/10.1111/joor.12242>, PMID:25270097
- [32] Ferrario VF, Serrao G, Dellavia C, Caruso E, Sforza C. Relationship between the number of occlusal contacts and masticatory muscle activity in healthy young adults. *Cranio.* 2002;20:91–8. <https://doi.org/10.1080/08869634.2002.11746196>, PMID:12002835
- [33] Kato H. The Function of Tooth Supporting Structures Part 2. The Dynamics of Molars in Function and at Rest. *Nippon Hotetsu Shika Gakkai Zasshi.* 1982;26:133–47. <https://doi.org/10.2186/jjps.26.133>
- [34] Parfitt GJ. Measurement of the physiological mobility of individual teeth in an axial direction. *J Dent Res.* 1960;39:608–18. <https://doi.org/10.1177/00220345600390032201>, PMID:14430405
- [35] Miura H, Hasegawa S, Okada D, Ishihara H. The measurement of physiological tooth displacement in function. *J Med Dent Sci.* 1998;45:103–15. PMID:11186196



This is an open-access article distributed under the terms of Creative Commons Attribution-NonCommercial License 4.0 (CC BY-NC 4.0), which allows users to distribute and copy the material in any format as long as credit is given to the Japan Prosthodontic Society. It should be noted however, that the material cannot be used for commercial purposes.